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ORIGINAL PAPER

Structure and components for the emergency response and warning system on Turtle Mountain, Alberta, Canada

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Abstract Since 2003, a series of over eighty sensors has been installed at Turtle Mountain, site of the 1903 Frank Slide. The purpose of these instruments is to both characterize and provide warning for a second large rock avalanche from the eastern face of the mountain, where various unstable masses have been identified. Although studies continue on the mountain to better understand the deformation patterns and interpretations of the slope kinematics, significant effort has been expended to develop a structure for the warning and emergency response that clearly outlines not only responsibilities and communications protocols during an emergency, but also day-to-day operational responses and procedures to ensure that the system remains operational. From a day-to-day operational perspective, a systematic and repeatable set of procedures is required in order to ensure that not only are data trends reviewed and reported on, but scheduled checks of system functionality are undertaken. An internal Roles and Responsibilities Manual has been developed to clearly outline responsibilities for geoengineering, information technology (IT), and management staff to ensure that system checks are completed and that support is in place on a 24/7 basis should components of the system cease to operate properly or should unacceptable deformations require review. In addition to that, a clear and concise troubleshooting manual has been developed. This document provides simple diagnoses of problems within the system and a clear roadmap of how to fix each component. From a warning and emergency response perspective, a series of color-coded alert conditions has been developed should unacceptable deformations be observed. At each alert level, clear responsibilities for actions and communications have been identified for geoengineering staff, provincial emergency management authorities, municipal officials, and first responders. This has been documented in the emergency response protocol. All documents described here are “living” documents that are updated on a regular basis as changes to the system are made. An annual mock warning exercise has been developed and run in

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order to test responses to a hypothetical emergency and generate updates to the system documentation.

Keywords Landslide · Early warning · Monitoring · Emergency response

Abbreviations

24/7	24 h/day, 7 days/week
AEMA	Alberta Emergency Management Agency
AGS	Alberta Geological Survey
AT	Alberta Transportation
BPB	Blairmore Provincial Building
CPR	Canadian Pacific Railway
Dgps	Differential Global Positioning System
EDM	Electronic Distance Measurement
EOC	Emergency Operations Centre
ERCB	Energy Resources Conservation Board
ERP	Emergency Response Protocol
FSIC	Frank Slide Interpretive Centre
GOA	Government of Alberta
GPS	Global Positioning System
IT	Information Technology
MEP	Municipal Emergency Plan
MCNP	Municipality of Crowsnest Pass
NOTAM	Notice to Airmen
RCMP	Royal Canadian Mounted Police
SLA	Service Level Agreement
SME	Subject Matter Expert
SOLGEN	Solicitor General
TMMS	Turtle Mountain Monitoring

1 Introduction

Located in southwestern Alberta, Canada (Fig. 1), Turtle Mountain is the site of the famous 1903 Frank Slide, which buried parts of the town of Frank and killed over 70 people (McConnell and Brock 1904). Subsequent studies (Allan 1931) of the remaining portions of the mountain highlighted a series of large cracks around the South Peak and the potential for another large rock avalanche to be mobilized. Studies by Allan (1931) and BGC Engineering Inc (2000) estimated that a failure of the mass at South Peak could potentially release a volume up to 5 million cubic meters of material and impact on municipal development and infrastructure below.

Although numerous attempts at monitoring the unstable areas (Anderson and Stoliker 1983; Cruden 1986; Fraser 1983; Kostak and Cruden 1990) have been undertaken since the early 1900s, there was not conclusive evidence of the overall movements of the peak and no way to provide a predictive warning should an acceleration of movements occur. In 2003, during a ceremony marking the centennial of the Frank Slide, the Government of Alberta (GOA) committed \$ 1.1 million (CDN) to design and deploy a real-time monitoring system

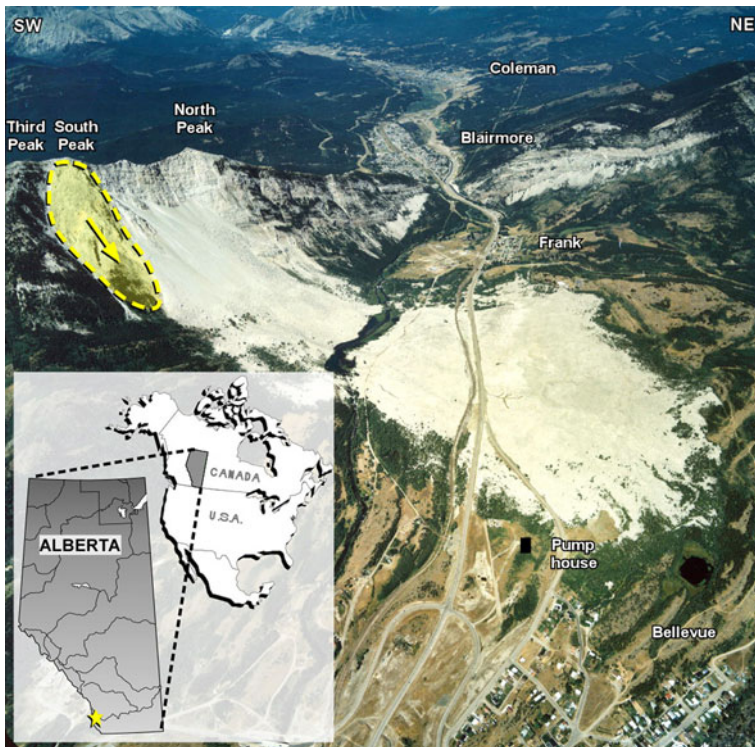


Fig. 1 Location of Turtle Mountain in Alberta (location indicated with a *star*) and full-extent aerial view of the Frank Slide. The dashed line below South Peak, Turtle Mountain, defines the area identified as being most unstable. Photographs reproduced with permission from Alberta Sustainable Resource Development, Air Photo Distribution. Image owned by the Government of Alberta and protected under the Copyright Act of Canada

and develop a warning and response plan for the Municipality of Crowsnest Pass (MCNP). This system was deployed between 2003 and 2005 (Read et al. 2005). Since 2005, the Alberta Geological Survey (AGS) has been responsible for the ongoing maintenance and expansion of the sensor network, interpretation of data, and developing internal protocols for early warning and emergency response. This study provides an overview of the structure of the monitoring and warning system and provides detail on the various components that are required to provide an effective response in the event of an emergency.

2 Project overview

The South Peak of Turtle Mountain is circumscribed by a series of long, deep cracks (Fig. 2), which are believed to have formed as a result of the 1903 Frank Slide. Detailed studies of the cracks and structure of the mountain led John Allan (1931, 1932, 1933) to estimate in 1933 that a second slide with a volume of approximately five million cubic meters could take place. Allan (1931) also used empirical relationships derived from the experience of the 1903 slide to estimate the potential run out zone for a second slide, with the worst case scenarios crossing both the highway and the Canadian Pacific Rail (CPR) mainline.

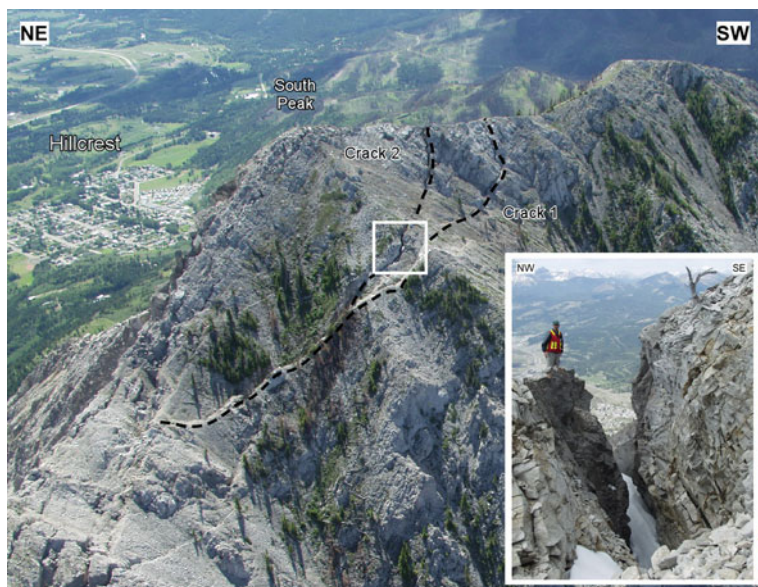


Fig. 2 Oblique view, to the southeast, showing the western side of South Peak, Turtle Mountain, and the two main large cracks (*dashed line*). Shown on *inset* view of the cracks from the ground with people for scale

Recently, more detailed assessments were carried out by BGC Engineering Inc (2000) and Hungr Geotechnical Research (2007, 2008) to provide a refinement of the run out estimations. However, these studies indicate the same elements, as outlined by Allan (1931), are at risk. In spite of the risk, development restrictions were never placed on the areas outside the 1903 slide. As a result, numerous residential developments were built in the potential run out zone. Figure 3 provides outlines of the various scenarios discussed earlier.

In an effort to manage the risk associated with a large rock avalanche from South Peak, the GOA commissioned the installation of a near real-time monitoring and warning system on the South Peak of Turtle Mountain (Read et al. 2005; Moreno and Froese 2006). Installation of the initial components of this system was completed in spring 2005, and overall responsibility for the long-term monitoring of the mountain then transferred to the AGS. Since then, significant effort has gone into assessment of the system functionality and reliability, review of the data stream, optimization of the system, and documentation of these items in a series of annual reports (Moreno and Froese 2006, 2008a, 2008b, 2009a, 2009b). As well, the AGS has also spent considerable effort in developing clear roles for short- and long-term responsibilities for system operation and maintenance (Moreno and Froese 2009a), responsibilities, and roles for staff during a heightened alert condition or emergency and worked closely with provincial and municipal emergency responders to develop clear plans for communications and roles in the event of an emergency (Alberta Emergency Management Agency 2008).

3 System functionality

In order to provide an effective warning system, there must be confidence that the system will function as designed on a near-continuous basis. To achieve this, there must be a

well-defined inventory of equipment and a well-defined chain of responsibility for reviews of the health of the system, including troubleshooting and contingency planning for repairs. The following sections outline the specific components and protocols for ensuring functionality of the system on Turtle Mountain.

3.1 Sensor network

Based on the recommendations made as part of the geotechnical hazard assessment by BGC Engineering Inc (2000), the monitoring system on Turtle Mountain was designed to include a number of different types of instruments communicating in near real time to a data acquisition center located at the base of the mountain. The design process involved defining the preliminary data requirements and reviewing options for instrument types and locations, measurement frequency, and equipment required for data acquisition and management. The monitoring network should provide complementary types of instruments with varying sensitivities to movement and climatic influences and also have enough redundancy built into the system to be able to distinguish real movement. At the end, the aim was to have a system that will provide a reliable data stream 365 days per year, 24 h per day in all weather and lighting conditions.

In considering the types of sensors most suitable for providing early warning for impending slope movements, the sensors were grouped into the following categories:

3.1.1 Primary sensors

The primary sensors are those which provide a reliable data stream on a year-round basis and that measure easily interpretable parameters of the rock mass such as length changes or rotation. The primary sensors include ten tiltmeters, five surface wire extensometers and twenty-two crack gauges. The surface wire extensometers and crack gauges measure absolute displacements with submillimeter level precision while the tiltmeters measure values of rotation in arc degrees. A list of the primary sensors, including their monitoring resolution, typical “noise” values, and threshold triggers, is provided on Table 1.

3.1.2 Secondary sensors

Secondary sensors are those that measure quantifiable parameters, but which may be subject to more variation due to environmental and other effects or have a coarser resolution than the primary sensors. These cannot be relied upon to detect the subtle onsets of movement. The secondary sensor network consists of twenty prisms with distance measurements shot from a robotic total station located in the base of the valley approximately 2.5 km from the upper eastern face of the mountain and twelve single-frequency GPS receivers. A list of the secondary sensors is provided on Table 1. Note that during normal operation, the secondary sensors are meant as primarily characterization tools and do not have thresholds assigned to them.

3.1.3 Tertiary sensors

Tertiary sensors provide background data that are useful in the interpretation of the results from the primary and secondary sensors. The tertiary sensor network consists of meteorological stations (rain, wind, temperature, barometric pressure) and web cameras on both the top and the base of the mountain, as well as an outflow weir at the base of the mountain.

Table 1 List of sensors (type and numbers, resolution)

Type	Category	Quantity	Resolution	Noise (standard deviation)	Alarm trigger threshold
Crack gauge	Primary	20	0.00625 mm	0.01 mm	5 mm
Extensometer		5	0.01 mm	0.5 mm	20 mm
Tiltmeter		10	0.0001%	0.005%	0.2%
GPS antenna	Secondary	12	0.1 mm	5 mm (htal)	
				15 mm (vcal)	
Prism		20	1 mm	10 mm	
Weather station					N/A
Wind monitor		1	Speed: 0.001 m/sec Direction: 0.1%	0.05 m/sec 0.5%	N/A
Temperature sensor		1	0.2°C	0.2°C	N/A
Rel. humidity sensor	Tertiary	1	0.01%	0.3%	N/A
Pyranometer		1	0.001 kJm ⁻² /h	0.002 kJm ⁻² /h	N/A
Barometric pressure sensor		1	0.01 kPa	0.02 kPa	N/A
Precipitation sensor		1	1 mm	~ 1 mm	N/A

Since the fall of 2003, a series of over 80 sensors has been installed around Turtle Mountain, with a large majority concentrated on South Peak (Moreno and Froese 2006, 2009c). The network of sensors and monitoring points installed on Turtle Mountain can be considered to span the full spectrum of monitoring as outlined by Larocque (1977). There are sensors and monitoring points installed at various points on the mountain to detect whether movements exist (Level 1), which aim to characterize areas of known movement (Level 2) and near real-time sensors to provide warning (Level 3). For the sensors and monitoring points on Turtle Mountain, the primary sensors are being used to provide warning (Level 3), whereas the secondary sensors are used to characterize movements (Level 2).

Continuous slope monitoring is very difficult particularly in the harsh and highly variable climate conditions at Turtle Mountain. As the sensors installed are very sensitive to deformation, they are also sensitive to temperatures fluctuations that will affect the normal operation of the instruments and must be considered in the interpretation of data. The primary and secondary sensors and their associated monitoring resolutions are shown in Table 1. However, numerous efforts are being made to increase the monitoring network reliability and this includes the addition of ground-based InSAR (Interferometric Synthetic Aperture Radar) technology (Alba et al. 2009; Arosio et al. 2009; Bozzano et al. 2008) in the fall 2009.

Figure 4 provides an overview of the type and distribution of sensors on Turtle Mountain, and Table 1 provides a list of the specific sensors and expected resolutions of each. More detail on the specifics and reliability of the various sensors has been documented by Moreno and Froese (2006, 2008a, b, 2009c).

3.2 Communication links

The success of any warning system relies not only on the adequate planning, design, and implementation of a series of instruments, but also on a proper data-management strategy.

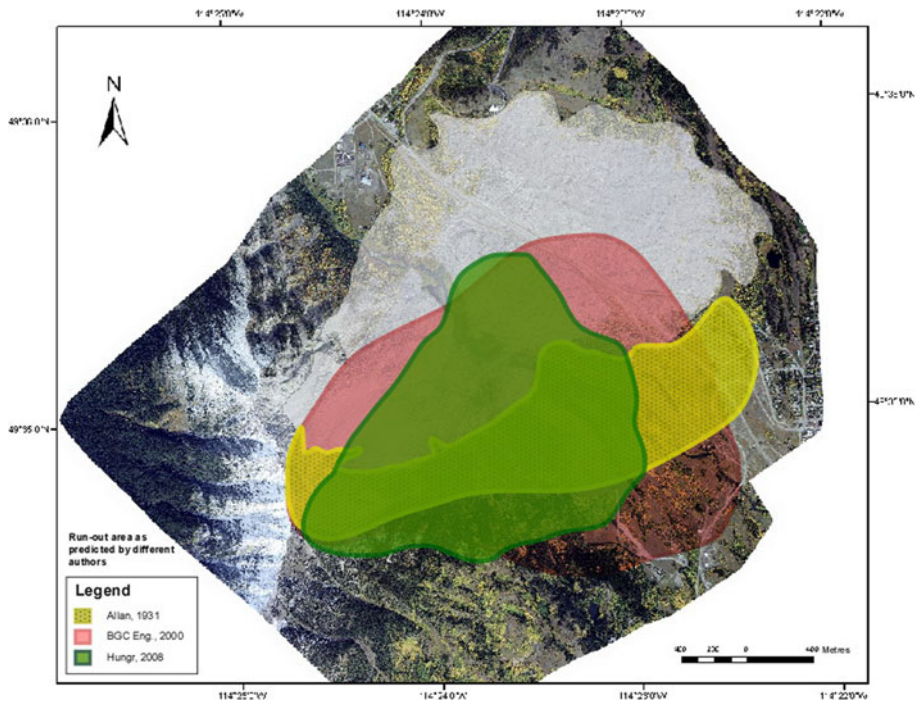


Fig. 3 Comparison between the boundaries of rock avalanche run out areas from the South Peak of Turtle Mountain as simulated by different authors

This section provides an overview of the various components of the data-management network as well as the different applications currently used for viewing data captured at Turtle Mountain.

3.2.1 Data transmission

On Turtle Mountain, several sets of instruments of varied complexity are continuously measuring and sending data. In considering how the data-management network handles these records, the data stream can be grouped into the following categories:

3.2.1.1 Primary data link This is the main link between the instruments on the west side of the mountain, where the primary sensors are located and the Provincial Building at Blairmore. This connection is done wirelessly. From there, data are relayed to the Frank Slide Interpretive Centre (FSIC) via a second wireless link. Data from this link cover both primary deformation sensors (crackmeters, extensometers, tiltmeters) and other sensors (dGPS, weather station, and thermistor string).

3.2.1.2 Secondary data link This data link covers wireless communications between the FSIC and the Bellevue pump house (Fig. 5), the location of the electronic distance measurement (EDM) system instrument. This link then covers the data feed from the EDM, which is collecting data from the twenty prisms (secondary sensor).

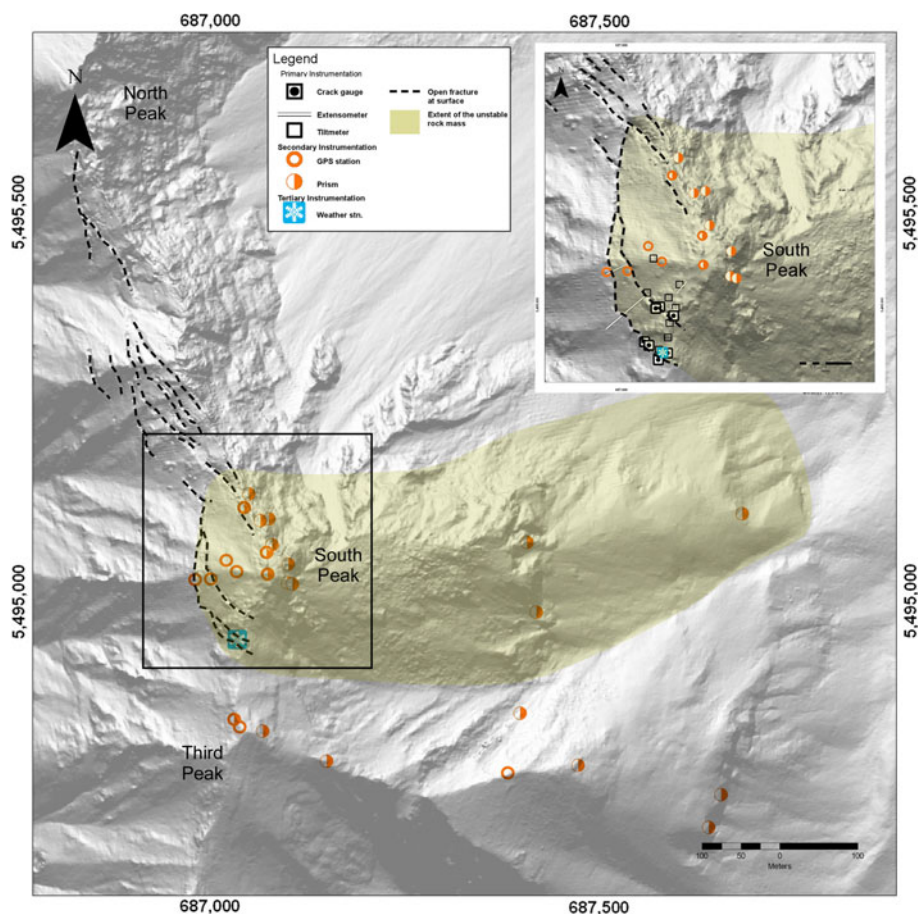


Fig. 4 Detailed overview of sensor network on Turtle Mountain

3.2.1.3 Tertiary data link This is the link between the FSIC and data transmission points located on the eastern side of Turtle Mountain. These data transmission points include spring-outflow measurements, three recently installed dGPS monitoring points, and images from a web camera installed at the top of Turtle Mountain.

All data streams received at the FSIC are written to a SQL server located in the basement, where it can be accessed over the Alberta Supernet connection by the Turtle Mountain monitoring system (TMMS) staff in Edmonton.

3.2.2 Data accessibility and redundancy

Remote data access is based on an Internet protocol, where the local data-management network is connected to the Internet by a router. This router acts as the main entry portal for monitoring the network. The network includes two main communications hubs: the Provincial Building at Blairmore and the FSIC. While the Provincial Building provides the wired connection to the Internet, the FSIC serves as the long-term data repository (Fig. 6). Overall, there are two main Internet links that provide broadband access to the data: the

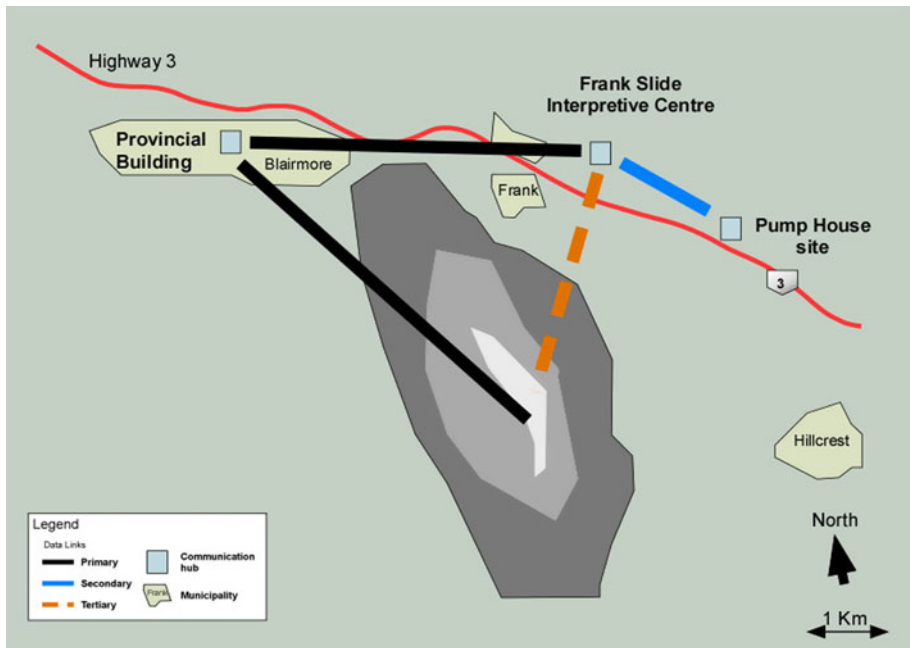


Fig. 5 Overview of communication links

Alberta Supernet and a commercial Internet provider. In the event that both Internet links fail, there is also access to the data loggers via direct connection from a personal laptop to the router at the Blairmore Provincial Building (BPB). This redundancy has been added to ensure there are at least two fall-back options to access the network are available in the event a main Internet link ceases to function. The sections below provide an overview of how these two Internet links are used to access data.

3.2.2.1 TM client There are two applications that are currently in use for viewing data captured at the FSIC. At regularly scheduled intervals, AGS staff access the data at the FSIC via a custom-developed application called TMClient, which pulls data not previously downloaded to an access database on a computer at the AGS/Energy Resources Conservation Board (ERCB) in Edmonton. These data are then pulled into an Excel spreadsheet for viewing and graphing of data. Excel is the primary application utilized in reporting data and evaluating data trends.

3.2.2.2 ATLAS The second application utilized to view data is a commercially available application called ATLAS (Durham Geo Slope Indicator 2009). The AGS currently subscribes to the web-based version of ATLAS that accesses the data from the loggers on the west side of the mountain and then copies it to a database housed by the company that provides the ATLAS monitoring service. Within the ATLAS web-based software, all of the instruments are displayed in a user-friendly manner on a plan view (photo) of the mountain. The sensors will display their latest measurements and the current alarm level (Fig. 7). By clicking on the measurement value, a trend plot will be created in a new window. This allows one to quickly view data from a single sensor.

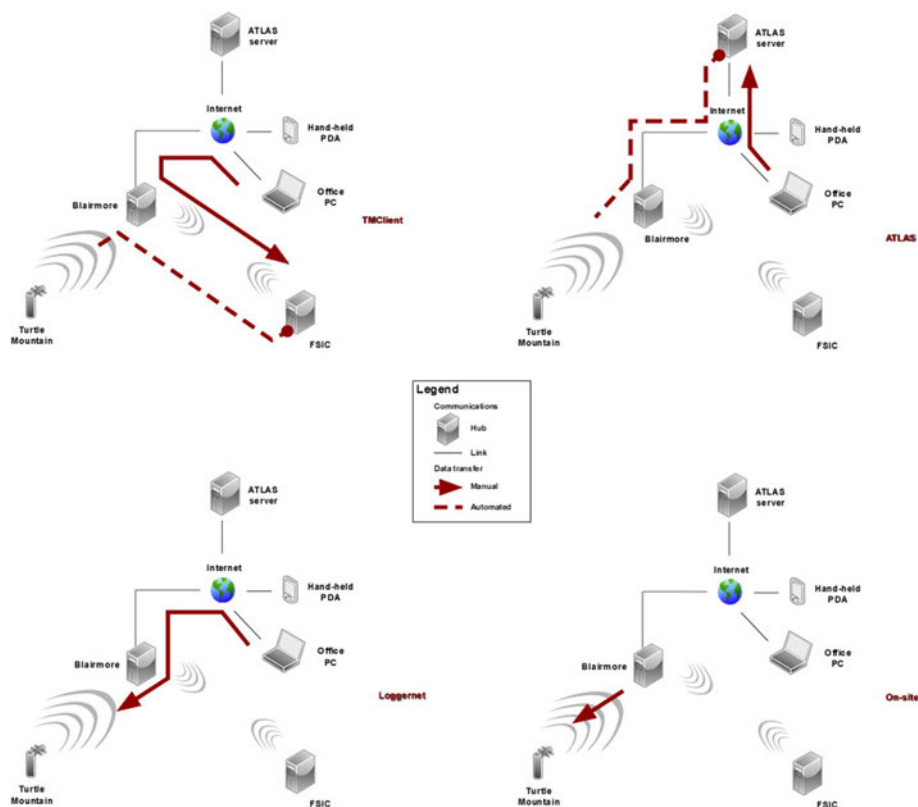


Fig. 6 Detailed schematic representation of the different data access strategies available for the Turtle Mountain monitoring project

If alarm levels have been set for a sensor, the information box on the plan view will change the color. Depending on its status, the following alarm levels are possible:

- Green—OK
- Yellow—warning level
- Red—alarm level

Table 1 provides an indication of the alarm levels set for each of the primary sensors. Annually, these values are shifted to take into account slow annual movements such that they are not triggered by slow movement over time but rather by a sudden movement. It is important to note that the thresholds are set in order to alert AGS staff to access and view the data from the sensors and not to trigger a change in alert level. Accordingly, these thresholds are set low enough to capture a significant movement but high enough not to be triggered by annual thermal fluctuations.

At the start of each working day, the ATLAS system is accessed by AGS staff to confirm operation. If it is not functioning and a trouble shooting routine cannot make it operational, then Loggernet (below) is utilized to access the data directly from the data loggers at the top of the mountain.

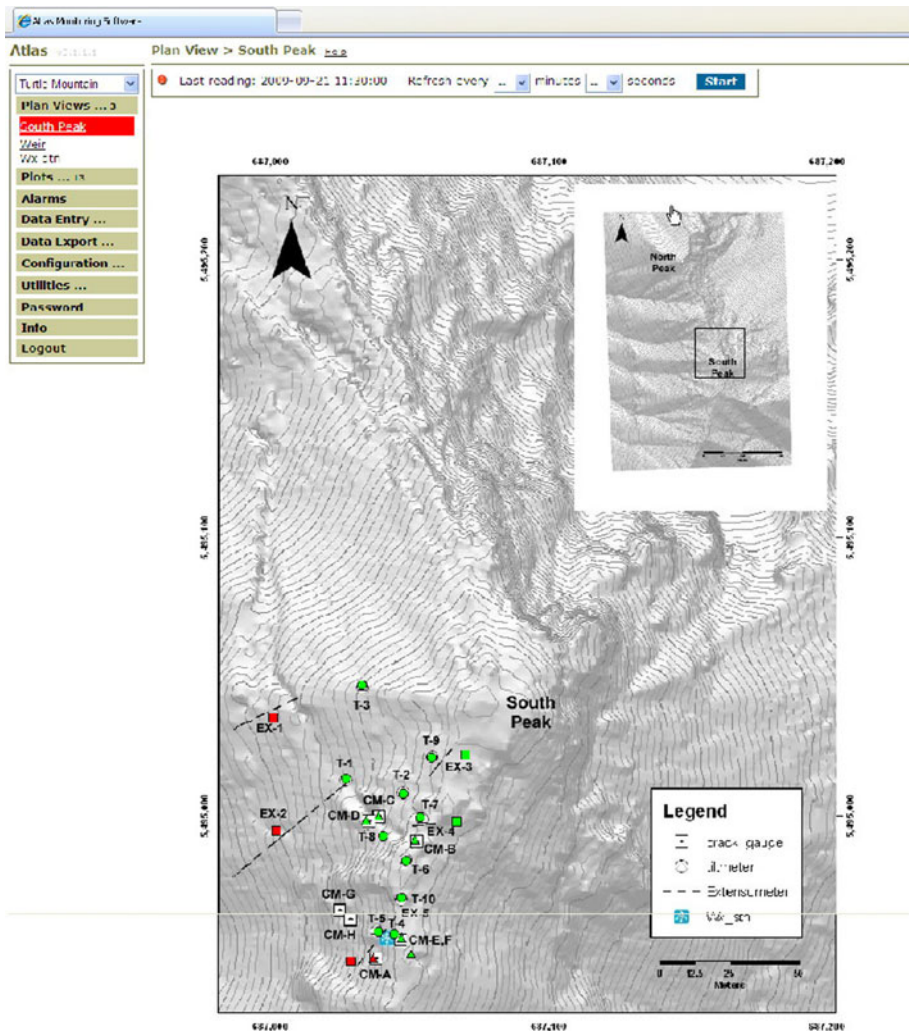


Fig. 7 Screen shot of ATLAS user interface, showing a plan view of the mountain with sensor location and their current alarm status. Depending on its status, the color of a data box can change from *green* to *yellow* to *red*

3.2.2.3 Loggernet Loggernet is a commercially available software application developed and distributed by Campbell Scientific (2009). This application can be used to log into a specific data logger, change settings, and/or download the near real-time stream of data from all sensors attached. On the western side of Turtle Mountain, there are two main data loggers (borehole and weather station) that collect data for a total of 37 of the primary deformation sensors. By logging in remotely via the commercial Internet link at the BPB or directly into the radios at the BPB (in the event of a disruption of Internet service), the real-time stream from the data loggers can be viewed and data can be downloaded.

3.3 Maintenance, diagnosis, and repair

The system health must be regularly reviewed in order to provide confidence that it will continue to function as required in an emergency situation. A well-defined plan for maintenance and repair is also required to reduce the potential down time for the system as well. The following provides the components of the TMMS system that address these issues.

3.3.1 Daily system checks

Although there is an automated web-based application to generate and distribute alarms via e-mail and voicemail (Sect. 3.2.2), a daily check of the health of the system is required. This process is assigned to a specific member of the team with backup persons specified for absences or vacation. The daily system checks are conducted at the beginning of each business day and consist of the following steps:

3.3.1.1 Daily

- check functionality of web cameras via web link,
- check data upload vis ATLAS web interface, and
- download from FSIC server using TM Client.

3.3.1.2 Weekly

- download of data using Loggernet.

The purpose of the above checks is to ensure that the redundant data transmission links are functioning and that the data stream from the mountain continues to perform as per design.

3.3.2 Annual inspection and repair

As the system is located on the top of a mountain in Canada, the peak is snow covered between late October and May. Therefore, every June a visual inspection of all installations is performed to confirm conditions and assess the need for maintenance and repairs. This is typically undertaken over a few days and involves AGS staff and any contractors deemed necessary. Conditions are documented, and lists of required equipment are compiled and ordered for a dedicated repair trip in late July. In addition to the annual inspection and repair trips, trips are also conducted when required to address system malfunctions that occur during the snow-free months. To date, system malfunctions have been of a limited enough nature during the winter months that sufficient numbers of component have remained functioning and are able to provide warning, and therefore, maintenance trips have not been conducted until late spring/summer. A decision as to how many operating sensors are sufficient to have an operational system is a judgement-based decision based on the type of sensors that are not functioning, the spatial coverage of the existing functioning sensors, and the previous movement data. There is no specific number that is available on which to make this determination. A complete overview of the system performance and maintenance is outlined in detail by Moreno and Froese (2006, 2008a, 2008b, 2009c).

3.3.3 System manual

Both for day-to-day operation and in an emergency situation, staff need to ensure that the system will continue to function. Therefore, it is important to be able to diagnose, troubleshoot, and repair every single component of the system from the on-mountain sensors to the network communication links. In a manner similar to manuals that come with consumer electronics, a system manual has been developed for the TMMS (Moreno and Froese 2009b). This manual is stored at a central location on the common computer network and in hard copy format with the team members and provides detailed step-by-step instructions to troubleshoot and repair each component of the system. This includes bullet form instructions and decision tree diagrams to lead the reader methodically through the steps. The system manual is a living document that is updated on real-time basis as changes to the TMMS are made.

3.3.4 Service level agreements (SLA)

It is important to ensure that the necessary expertise is available to provide assistance in the repair and maintenance of the system components during normal operation and in an elevated alert condition. As it is not often practical to have expertise in geology, geomechanics, instrumentation, computer hardware, and networking and communications under one roof, agreements must be put in place with other groups or organizations. For the TMMS, official agreements have been developed and approved by management that confirm the availability of qualified personnel at a specified time to troubleshoot and repair components of the computer and networking equipment on the mountain. Table 2 provides an example of the response times in the SLA, as they correspond to the alert conditions.

4 Data review

It is important to determine who reviews data, on what frequency, how data are evaluated, and how threshold exceedance is determined. The following outlines the various aspects of data review implemented for the TMMS.

Table 2 Maximum allowable down time for software and network equipment associated with the various access data methods (links) at the different alert levels

Link	Access point	Data	Maximum down time ^a			
			Green	Yellow	Orange	Red
A	Blairmore (west side of Turtle Mountain)	Primary	3 days	1 day	1 h	1 h
B	FSIC ^b (east side of Turtle Mountain)	Secondary/historical Data	5 days	2 days	1 day	1 day
C	FSIC (east side of Turtle Mountain)	Tertiary	5 days	2 days	1 day	1 day

^a Measured from the time that IT network group has acknowledged the call

^b Frank Slide interpretive center

4.1 Data review procedure

Once data have been obtained, transmitted, and uploaded, a protocol must be in place to ensure that data are reviewed on a specified frequency and in a repeatable manner. This data review protocol comprises the overall strategy for plotting, reviewing, interpreting, and acting upon data from the sensors installed on South Peak of Turtle Mountain. The frequency of review ranges from daily checks of the completeness of the data to annual reviews and interpretation of the data trends.

4.1.1 Daily

A check, during normal business hours, that the critical data transmission links are functioning and data are being transmitted from the mountain and stored on the database. This responsibility is assigned to a member of the project team with a backup for days that the staff member is away due to schedule timed off or sick time.

4.1.2 Weekly

A PDF report is automatically generated from the ATLAS software on a weekly basis and distributed to the project team. The report itself consists of measurement data in the form of preconfigured graphs and alarms of the previous week.

4.1.3 Yearly

A complete review of the data trends for the entire system with interpretation of the movement trends in relation to the visual observations on the mountain. Annual data review and interpretation of the Turtle Mountain monitoring project can be found in the study by Moreno and Froese (2006, 2008a, b, 2009c).

4.2 Threshold determination and exceedance review

This component includes the establishment of thresholds against which the results obtained from the sensors are evaluated. The challenge in the development of thresholds on newly installed instruments, as in the case of Turtle Mountain, was to provide initial trigger alarm levels that are neither too conservative, leading to numerous false alarms, nor fail to catch real events and provide adequate warning. Due to the limited baseline information on the deformations at South Peak, the development of thresholds was largely based on a review of the literature and experience with similar monitoring projects on other sites throughout the world.

There are two main types of instrumentation thresholds that should be considered. Exceedance of these thresholds will result in an alarm condition and/or change in alert level:

4.2.1 Absolute thresholds

These are specific values that are set typically based on two to three standard deviations above the instrument noise and/or known seasonal thermal fluctuations of the sensors and rock mass. As ongoing movement occurs, it may be necessary to reset the absolute threshold. Table 1 provides a listing of the absolute thresholds chosen for the various

sensors based on the past performance of the sensors and understanding of the seasonal thermal fluctuation trends.

4.2.2 Velocity-based thresholds

Velocity-based thresholds consider the rate of movement or rate of change in the rock mass/reading. These types of thresholds are often expressed in millimeters per day or week and are based on the experience-based judgment of a rock slope engineering specialist.

Only absolute threshold levels are provided for the instruments at Turtle Mountain. At this time, no attempt has been made to undertake analyses to determine velocity thresholds due to the complex nature of the rock mass and the influence of seasonal fluctuations on the readings. As outlined by Crosta and Agliardi (2003), the development of a model to predict failure breaks down when external conditions that vary with time and deviations induced by seasonal and meteorological variations take place.

5 External warning and emergency response

The essential function of the AGS staff is to determine what constitutes an emergency situation and when external stakeholders need to be notified. This requires a clear understanding of what rate and extent of deformations on the mountain are unacceptable and a clear line of communications to pass information to emergency responders and municipal officials.

5.1 Alert condition stages

Based on the data obtained since 2003, the South Peak of Turtle Mountain is moving slowly (millimeters per year) and is expected to move slowly until it accelerates prior to collapse. Based on a review of data for similar topography and geology, it is expected that there would be days to weeks or months of warning of a catastrophic collapse. Blikra (2008) provides a schematic diagram of the expected velocity trends prior to collapse and the alert conditions associated with each. A modified version of the schematic diagram is presented in Fig. 8 as it applies to the expected velocity trends and related alert conditions at Turtle Mountain.

Each alert level is associated with an appropriate level of action. The alert framework may require adjustment based on experience. In addition, particular circumstances may require deviations from the actions suggested below. The sections below provide specific details on the responses for the various alert levels as originally outline by Froese et al. (2005). These are based on similar alert conditions utilized for volcano warning system in western North America (Hill et al. 2002).

5.1.1 Condition green (normal operations)

A green condition is the alert designation for normal operations including regularly scheduled data review (Fig. 9) and field checks when at least one of the following conditions is met:

- There are no deformations above specified thresholds, and the system is functioning properly.

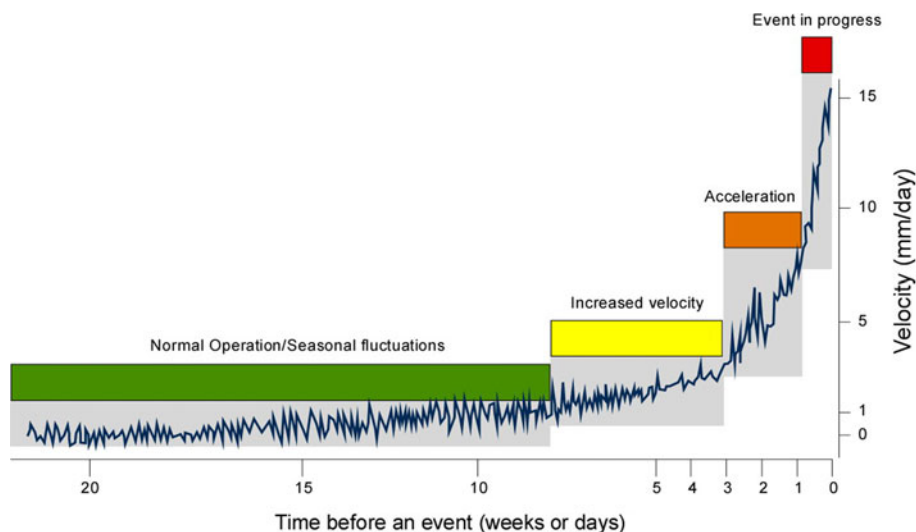


Fig. 8 Schematic velocity/alert level sketch (after Blikra 2008)

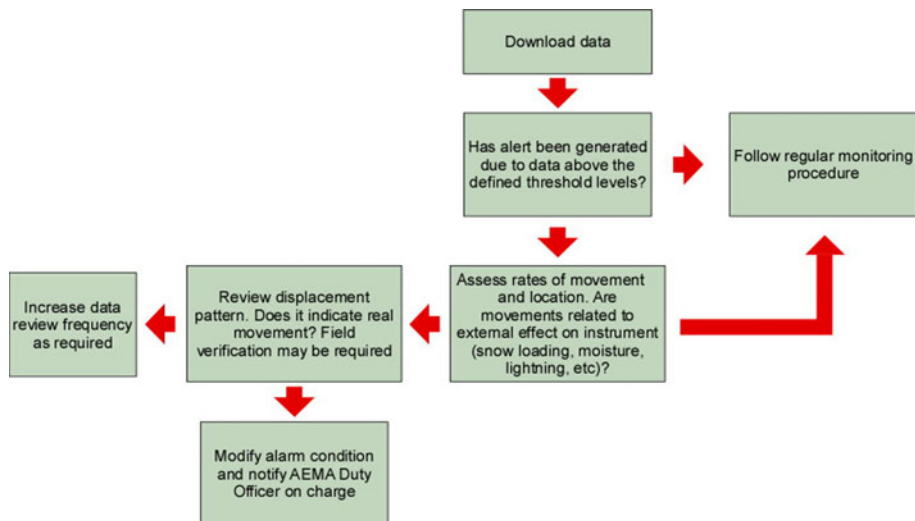


Fig. 9 Threshold review alert decision tree

- A threshold exceedance is detected on a single sensor, but it is determined by AGS geotechnical personnel that this is indicative of instrument error, vandalism, or climatic influence, or the exceedance is due to a local condition that is not considered to be a problem with respect to overall rock mass movement conditions;
- Trends are observed on a number of instruments that are deemed by the AGS to be within acceptable limits thus not requiring notifications to the AEMA nor changes in alert levels.

During the green alert level, regular data summary reporting is completed and no additional notifications would be necessary. System repairs and calibration checks are also undertaken on an as-needed basis.

5.1.2 Condition yellow (watch)

Should a trend of systematic deformations be observed on a number of sensors and the AGS identifies that these are likely indicative of slope deformation and not due to climatic or other non-slope effects, and then a watch (condition yellow) would be called. Under a watch, the AGS geotechnical personnel would phone the AEMA Duty Manager, indicating that movements are still below levels of concern and that these agencies would be provided with updates on a daily/weekly basis until the alert level is either lowered or raised. The AEMA Duty Manager then notifies the MCNP and the AEMA District Officer of the alert condition change, but no other specific action are required.

Under a watch, the recommendations by the AGS may include, but are not limited to the following actions:

- Increasing the frequency of reviewing monitoring data;
- Increasing the frequency of data acquisition;
- Site reconnaissance/investigation (not required, discretionary at condition yellow);
- Further analysis (perhaps with supplemental information from other sources, e.g., InSAR); and
- Lower, maintain, or raise current alert level.

From these recommendations, AGS will make a decision to lower, maintain, or raise the alert level and initiate the necessary actions. If an alert level is raised to a warning (condition orange) or greater, there must be follow-up of the recommended action items to ensure that the integrity of the system is not compromised. Any change in alert condition is relayed via telephone to the AEMA Duty Manager. Until threshold values are established, there needs to be frequent and open discussions between the geotechnical specialist and the internal government resource carrying out the regular data review.

5.1.3 Condition orange (warning)

In the event that the systematic deformations accelerate and visual observations of the progression of slope movement are made, then the AGS geotechnical engineer raises the alert level to a WARNING (condition orange). Under an orange warning condition, deformations on the on South Peak are accelerating, leading to concern of a possible future failure of significant portions of the peak or of the entire peak.

Under this alert condition, the AEMA Duty Manager is notified by telephone that they should begin notifying the public (both recreational users and residents) in the vicinity of South Peak that a failure on South Peak may occur. Other appropriate actions such as public advice notices and evacuation preparation may be required as outlined under the municipal emergency plan.

Due to the very serious nature of this condition and the fact that the public will be notified, it is imperative that the determination of the warning is to be made with input by the AGS geotechnical engineer based on the instrumentation results, visual observations and judgment based on specific experience with rock slope failures, and interpretation of data on other projects. The misdiagnosis of warning could lead to either a catastrophic

collapse, not being detected in time, or the public believing that the system is unreliable resulting in a loss of confidence.

At this stage, the message to be relayed to the AEMA Duty Manager is that there is a concerning acceleration of slope movements on the South Peak and that the public in the affected areas be notified with recommendations for voluntary evacuations. It is most likely that an orange condition is reached after ongoing deformation of the peak. However, if the deformations occur in the evening or under snow or poor visibility conditions, visual assessment may be impaired and consideration of whether a mandatory evacuation order should be issued until a detailed assessment could be undertaken. As the worst case empirical estimate for a rock slide run out incorporates the highway and railway, it is required for AEMA to notify Alberta Transportation (AT) and CPR.

During the condition orange, the AGS geotechnical engineer is available to act as the Subject Matter Expert (SME) to provide briefings to AEMA and the MCNP as to the technical details of the assessment and relay any changes directly to these parties during the event.

5.1.4 Condition red (failure)

In this stage, it has been confirmed based on the instruments and detailed visual assessment (may require a safe vantage point such as a helicopter) that a catastrophic collapse of the South Peak appears to be imminent (within 1–3 days). At this stage, the alert level would be raised to red, and the message delivered from the AGS to the AEMA Duty Manager is that a catastrophic failure of all/a portion of South Peak is underway and that the potential affected area should be evacuated, highway and rail traffic completely restricted and emergency response personnel should be mobilized to control access and remain a safe distance from the potential run out areas. The information flow during this stage from the AGS/ERCB to AEMA remains as in condition orange with the external specialist on site and providing liaison with AEMA and the municipality as the SME.

5.2 Communications (internal and external)

Effective response in the event of an elevated alert condition cannot be undertaken unless there are clearly defined roles at the various levels of organizations involved. The following provides an overview of the determination of roles and responsibilities that involve any emergency response related to Turtle Mountain.

5.2.1 Internal roles and responsibilities

The AGS is responsible for determining the appropriate alert level for a potential or actual emergency at Turtle Mountain and for providing technical expertise to the provincial and municipal emergency responders during an event. It is therefore important that timely and efficient information review and delivery both internally to ERCB and externally to AEMA be completed. In order to coordinate response from within the organization to external organizations, a detailed manual outlining the roles and responsibilities of all involved staff members has been developed (Moreno and Froese 2009a).

This document establishes the chain of command, identifying key individuals at ERCB who will fill each position and clearly defining their roles and responsibilities so they can effectively manage any alert situation. A hierarchy is also defined for reporting

rock-displacement alerts and other critical information to appropriate individuals at each stage of the response. Development of this communication structure was based on the recommendations in the training material produced by United States Environmental Protection Agency (2003). It should be noted that the number of people notified will increase as the level of alert rises and decrease as it moves toward its completion (e.g., all communications and notifications are internal during alert level green). To avoid false alarms, any call for a modification of the alert level must be evaluated in the context of typical seasonal fluctuations in displacement and experience gained over time in interpreting those fluctuations. This plan is designed to consider a careful evaluation of a displacement alarm and to have the appropriate response based on that evaluation.

As part of this document, there is a clear flow of communication for notifications that involves external parties, information technology support, technical specialists, and management. For the communication linkages, there are alternate notifications should key members of the team be unavailable. Figure 10 provides a communication flow diagram that would be followed should an alarm be generated by the ATLAS server.

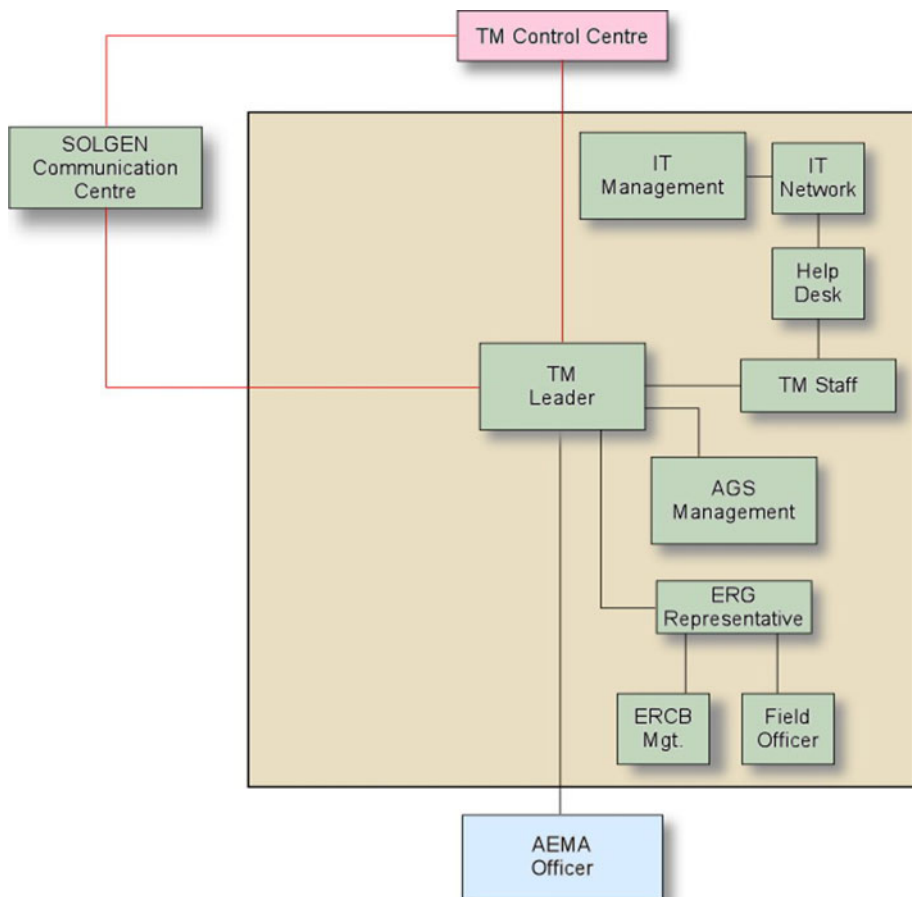


Fig. 10 Internal communication flow

For this structure, there has been an external party, the solicitor general's (SOLGEN) office that runs a 24/7 emergency desk, whose role is to verify that any alarm generated automatically from the ATLAS server had been received and addressed by a member of the TMMS. The SOLGEN would call a list of TMMS team members (office, mobile, home) until a response is received and then document who had acknowledged the response. There are also other levels of communications within the organization (ERCB) and externally to the AEMA.

5.2.2 External communications

Once an alert condition is raised to a warning (orange), providing communication of the change to affected residents or stakeholders becomes the responsibility of municipal and provincial emergency management officials. At the conclusion of the sensor network implementation in 2005, an emergency response protocol (ERP) was developed to ensure a coordinated series of actions between various orders of government and the private sector. This protocol provides that coordination between the provincial emergency management agency, other provincial agencies, industry stakeholders and the municipality, and other possible participants at the provincial and federal order of government. While the municipality has its own Municipal Emergency Plan (MEP) that includes evacuation protocols and tasks for municipal officials, first responders etc., this protocol is designed to ensure the relevant organizations are notified and that appropriate coordination follows to ensure the MCNP received the assistance and information they require to respond to and recover from a slide emanating from the South Peak of Turtle Mountain.

The ERP is based on Alberta's emergency management framework, which specifies that the coordination of emergency management response and recovery begin at the municipal order of government and escalated as required. The MCNP will take the required action in accordance with its MEP. In accordance with the ERP call tree, AEMA will make the necessary calls to relevant GOA ministries and private sector companies that will be directly affected by a slide (e.g., RCMP, CPR etc.). This call down will begin at level orange, though individual organizations may be warned depending on input from the AGS/ ERCB technical expert. The AEMA District Officer will move to the MCNP Emergency Operations Centre (EOC) to provide assistance and advice as required, as well as performing his standard liaison function with the AEMA EOC in Edmonton. This liaison function will include informing the AEMA EOC of any additional resources and assistance required by the MCNP that cannot be acquired through normal channels or via mutual aid agreements. Figure 11 provides a schematic of the function and communication flow that would apply for alert conditions orange and red, as per the ERP.

5.2.3 Mock exercises

In order to review validity of the response plans over time and to provide a refresher to existing staff and training for new staff, it is important to incorporate an annual emergency exercise of some type. Gebbie et al. (2006) outline two main types of exercises: discussion-based and operation-based. Discussion-based exercises are considered to be the starting points in a building block approach to exercises (Gebbie et al. 2006) and are primarily used to familiarize internal staff with existing plans and capabilities. Operation-based exercises are more involved and are used for the purpose of assessing and validating emergency preparedness policies, plans, and procedures and include drills, functional exercises, and full-scale exercises (Gebbie et al. 2006).

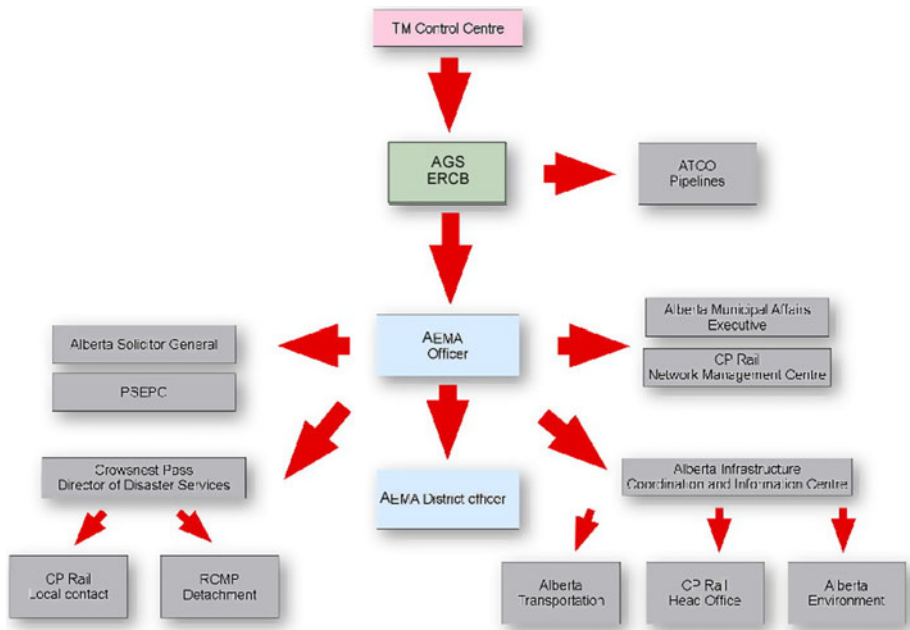


Fig. 11 External communication flow

For the TMMS, both levels of exercise have been undertaken. On an annual basis, a discussion-based exercise is undertaken within the organization involving members of the TMMS team, corporate security, IT, and the emergency response group. This exercise is classified as a table top and consists of a group working through a series of scenarios with verbal discussion of the roles and responses for each scenario. It also serves as an opportunity to reaffirm management commitment to resources (financial and human) to the TMMS.

In addition to annual exercises to refresh the members of the AGS and parent organization, a larger operation-based exercise has also been undertaken including all of the organizations that would be mobilized in the event of an elevated alert condition. This includes the provincial emergency management agency, municipality, first responders, utilities, transportation department, railway, and members of the TMMS team. For this exercise, there are three groups: a simulation group, a site group, and the EOC. The simulation group is charged with developing scenarios that are fed to the members of the EOC group. The EOC group would then interact real time to make decisions as to response and communicate any changes in status or instructions to the site group. The site group is responsible for talking through actions that would happen away from the emergency operations center, such as evacuations and road closers. Members of the TMMS team are situated in both the EOC and simulation room for the exercise (up to 3 h) with the TMMS member at the EOC acting as the subject matter expert to update the status of the movements on the mountain. The exercise is then followed by a debriefing of all participants in order to document the key lessons learned.

6 Discussion

For most geoen지니어ing professionals involved with the characterization and monitoring of hazards, the main considerations are about the types of sensors, interpretation of data, and development of alarm thresholds. When considering the development of alarm thresholds and the selection of appropriate sensors on which to base this, the following should be considered:

1. **Evolution of Sensor Priority:** As there are many different technologies and resolutions that are available to monitor displacement, there may be a different focus on various sensor types over the life of the monitoring. On Turtle Mountain, while sensors such as crackmeters with submillimeter resolution are valuable in understanding the pre-failure displacements, their working range is exceeded long before catastrophic movements develop. On the other end of the spectrum, like GPS, have a much coarser resolution will shift from secondary to primary monitoring technologies once movements exceed centimeters to decimeters. Therefore, over the life of a monitoring project, the reliance on differing monitoring technologies will evolve.
2. **Setting Automated Threshold Values:** The determination of what level to trigger an alarm on a specific sensor is not trivial. Not only do various sensors and monitoring technologies have differing lower monitoring resolutions, but also they are impacted differently by climatic factors. For Turtle Mountain, in the absence of any baseline data, the trigger thresholds for alarm generation were two standard deviations beyond the “noise” level generated during the first few months of operation. Table 1 provides the standard deviation of the noise observed for each sensor and the threshold chosen for an alarm trigger. The alarm trigger is set far below the deformation level where concern for movements would be likely, but it is intended to provide a computer-generated alert to the TMMS team to check the sensor data. In the event of an acceleration of a large portion of the mountain (alert conditions yellow to red), near-continuous expert review of data would be utilized to generate changes in alert conditions and alarms to stakeholders, rather than the use of pre-set threshold values.
3. **Importance of Understanding the Mechanism for Movement:** In continuing with the above-mentioned discussion of trigger values and alarms, an understanding of the movement kinematics is required when interpreting the data and making decisions as to alarm conditions. In the case of Turtle Mountain, numerous single- and multiple sensor alarm triggers have been the result of climatic inputs (lightening, ice) or movement of isolated blocks. These cases have highlighted the importance of looking at the entire array of monitoring points along with a clear picture of the mechanism to make decisions. For Turtle Mountain, recent studies by Froese et al. (in press) and Pedrazzini et al. (in press) have utilized airborne LiDAR data and field mapping to map unstable volumes on the eastern face of the mountain. These studies have highlighted that the initial assumptions of the mechanics and the volume of movement made by Allan (1931) in fact may be overly pessimistic, and in fact, it is more likely that the eastern face of the mountain may fail in smaller volumes and therefore pose less of a hazard. It is important to use this updated understanding when reviewing data from discrete monitoring points.

This study outlines the important considerations in ensuring that the data can be obtained and reviewed in a reliable and repeatable manner and that the population at risk receives timely notification in order to avoid the hazard, thus mitigating the risk. The specific example of the TMMS has been used to illustrate the structure of the system that is

required to provide warning and response for a rock slide at Turtle Mountain. For the Turtle Mountain monitoring system, although this paper has focussed on the description of the infrastructure in place to provide warning, perhaps, the largest challenge of this type of project is non-technical. For the specific case of Turtle Mountain, the rates of movement are so slow (millimeters per year) that it is easy for the technical team, organizational management, and stakeholders to lose interest in the monitoring and warning project. Currently, the TMMS is in its sixth year of operation, and the financial expenditures have decreased significantly as the system has become operational, and the focus has shifted to more reliable and robust monitoring technologies. It is currently planned to have a formal review panel formed and an evaluation of the future of the monitoring and warning system undertaken in 2013 at the end of the first decade of monitoring to provide guidance as to the risk and future effort.

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